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14. ABSTRACT

The objective of this project is to implement an electron spin qubit system on a silicon metal-oxide-semiconductor platform. The logic qubit is formed by three individual spins in electrostatically-defined quantum dots. The gate operations are carried out by spin exchange interactions alone. The project started in November 1, 2010, aims to provide a technological base for a scalable qubit system which is fully compatible with commercial Si CMOS technology. During the funding period, we have successfully developed an array of highly stable Si MOS triple

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Report Title

Final Report: Development of a Silicon Metal-Oxide-Semiconductor-Based Qubit Using Spin Exchange Interactions Alone

ABSTRACT

The objective of this project is to implement an electron spin qubit system on a silicon metal-oxide-semiconductor platform. The logic qubit is formed by three individual spins in electrostatically-defined quantum dots. The gate operations are carried out by spin exchange interactions alone. The project started in November 1, 2010, aims to provide a technological base for a scalable qubit system which is fully compatible with commercial Si CMOS technology. During the funding period, we have successfully developed an array of highly stable Si MOS triple quantum dot devices. We have carried out an ESR spectroscopy to measure the in-homogenous decoherence time of individual electrons and to directly probe the spin-valley mixing in a Si MOS double quantum dot device. We have studied the gate/charge noise of the devices and found to be a bit smaller than similar SiGe QD devices. Preliminary, fast-pulse, experiments are carried out to manipulate and read-out the basis states of the triple quantum dot qubit. Our experimental investigations show encouraging results for the further development of spin-based qubits in Si MOS structures.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
03/31/2016	3.00	Xiaojie Hao, Rusko Ruskov, Ming Xiao, Charles Tahan, HongWen Jiang. Electron spin resonance and spin–valley physics in a silicon double quantum dot, Nature Communications, (05 2014): 0. doi: 10.1038/ncomms4860
03/31/2016	4.00	Ming Xiao, M. G. House, GuoPing Guo, HaiOu Li, Gang Cao, M. M. Rosenthal, HongWen Jiang. Detection and Measurement of Spin-Dependent Dynamics in Random Telegraph Signals, Physical Review Letters, (09 2013): 0. doi: 10.1103/PhysRevLett.111.126803
08/31/2011	1.00	M. House, H. Pan, M. Xiao, H. W. Jiang. Non-equilibrium charge stability diagrams of a silicon double quantum dot, Applied Physics Letters, (09 2011): 0. doi:
08/31/2012	2.00	M. G. House, X. Hao, H. W. Jiang, H. Pan. Fabrication and characterization of a silicon metal-oxide-semiconductor based triple quantum dot, Applied Physics Letters, (2012): 0. doi: 10.1063/1.4731275
TOTAL:		**4**

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

1. HongWen Jiang, "Measurement and control of individual electron spins in Silicon MOS-based quantum dots", Quantum Control of Solid State Systems Workshop, Princeton, NJ, November 3, 2011.

2. HongWen Jiang, "Physical implementation of quantum information processing based on individual electron spins in semiconductors", Physics Colloquium, Pomona College, December , 2011.

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7. HongWen Jiang, "Exploration of Si MOS Based Qubit", Invited talk in The 1st International Workshop on Frontiers in Quantum Optics and Quantum Information: Quantum Computing with Electron Spin Qubits, July 4, Beijing, China 2014.

Number of Presentations: 7.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

<u>Received</u> <u>Paper</u>

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

<u>Received</u> <u>Paper</u>

TOTAL:

Number of Manuscripts:

Books

<u>Received</u> <u>Book</u>

TOTAL:

Received Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Hong Pan	0.80	
Blake Freeman	0.50	
Joshua Schoenfield	0.50	
Matt House	0.10	
FTE Equivalent:	**1.90**	
Total Number:	**4**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Xiaojie Hao	0.10
FTE Equivalent:	**0.10**
Total Number:	**1**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
HongWen Jiang	0.10	
FTE Equivalent:	**0.10**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED	Discipline
Nora Brackbill	0.00	physics
FTE Equivalent:	**0.00**	
Total Number:	**1**	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: 1.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME	
Hong Pan	
Matt House	
Total Number:	**2**

Names of other research staff

NAME	PERCENT_SUPPORTED
New Entry	0.00
Niels Thompson	0.00
FTE Equivalent:	**0.00**
Total Number:	**2**

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

See attachment

Technology Transfer

Final Report

Development of a Silicon Metal-Oxide-Semiconductor-Based Qubit Using Spin Exchange Interactions Alone

Principal Investigator: HongWen Jiang

University of California, Los Angeles

Introduction

Quantum dot devices build on Si MOS platform are attractive for quantum information processing. The main reason is that the Si MOS QDs fabrication process can be fully compatible with commercial Si CMOS technology. One should be able integrate qubits with the more conventional CMOS analog/digital electronics on chips, both for advanced pulse control and for high-speed read-out. Furthermore, Si MOS QDs should be able to take advantage of the long spin phase-coherence times of Si.

Our current project, started November 2010, aims at the physical implementation of a particular type of qubit in the Si MOS system so that one can possibly take advantage of the very long spin coherence time expected in Si, the extremely high charge stability in single electron MOS devices, and its compatibility with main-stream semiconductor infrastructures. In 2000, DiVincenzo and coworkers proposed a Heisenberg exchange-interaction-only spin qubit system.[1] In this proposal, each logic bit is formed by three exchange coupled spins. The exchange interaction only gate operations have several marked advantages. First, it removes the needs for a microwave field, or an inhomogeneous magnetic field with orbital motions, that are required for single-bit rotations of a spin qubit based on the Zeeman sublevels. Currently, the incorporation of local microwave fields in QDs remains a big technical challenge. Second, since the Heisenberg exchange coupling is a strong interaction, which can have a frequency of >10 GHz, the gate operations can therefore be extremely fast (as fast as 0.1 ns). The speed of this gate operation can be much faster than that given by ESR rotations, which require a very strong microwave magnetic field component. Furthermore, as the exchange coupling is highly local it can be turned on and off selectively by an electrical static potential which can be readily provided by a single surface gate in the semiconductor QD. The experimental demonstrations of such qubits were made in GaAs based triple quantum dot (TQD) devices [2,3,4] The recent

successful demonstration of a new scheme to better manipulate the exchange-only qubit using a pulsed RF source [5], known as a resonant-exchange-qubit [6,7], in GaAs further improves the prospect of the exchange-only qubits for scalable applications.

During this funding period, we have made steady progress towards our objectives. The exchange based qubit in Si MOS QDs, in our optimistic opinion, is now about one or two years away from surpassing the state-of-the-art in GaAs QDs. Our main accomplishments in this period are highlighted below.

(1) Development of a robust electrostatically-defined Si MOS triple quantum dot device

Since the logic qubit is formed by three individual spins, it is critical for us to fabricate an electrostatically-defined triple quantum dot. Building progressively upon our development of single QD [8] and double QD [9] at PI's Lab at UCLA, we have successfully fabricated Si MOS triple quantum dot devices, after several generations of gate-pattern iterations and testing, for over 14 batches of devices, over the period of 1.5 year of intense fabrication effort. We have demonstrated the ability to reach the electron number configurations of (0,0,0), the vacuum state, and (1,1,1) in which there is only a single electron in each QD [10]. The TQD is highly tunable. For the last few electrons, we can consistently tune two triple points into a quadruple point [10], as shown in Fig. 1. We can also gate control the tunnel coupling over a broad energy range. The ability to reach quadruple points in the last few electron regimes indicates its promise for controlling the exchange interactions between the three dots and for demonstrating all-electrical control of a spin qubit in silicon.

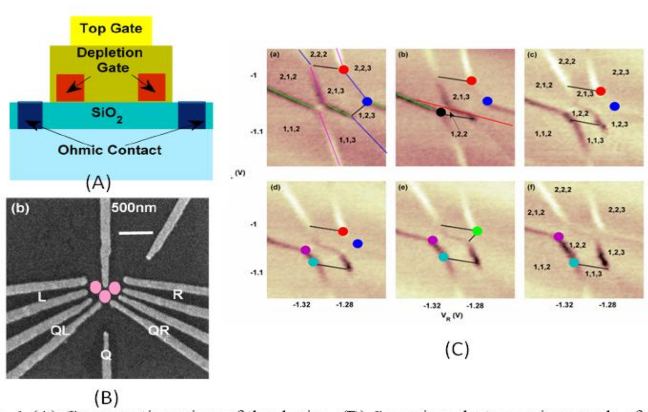

Fig. 1 (A) Cross-section view of the device. (B) Scanning electron micrograph of depletion gates layout of a TQD device. (C) Evolution of achieving quadruple points. (a)-(f), V_{QR} is increased by 3mV each frame. For example, two triple points, where middle and right dot (red) and left and right dot (blue) are on resonance, are brought together to a quadruple point (green) in (e).

(2) ESR spectroscopy of individual spins in Si MOS QD and measurement of inhomogenous decoherence time

We have obtained the inhomogenous decoherence time of individual electron spins in Si MOS QD. It is currently an open question whether the stochastic spin fluctuations of the structural defects near the Si/SiO_2 interface may ruin the long-coherence time one may expect for a pure silicon crystal. In an experimental effort, partly, we have detected electron spin resonance (ESR) in a Si MOS double quantum dot. Pauli spin blockade is used as a means to detect the flip of spins. The microwave driven ESR signals, with a linewidth as narrow as 0.7 G, has been observed, which is strikingly small comparing to that of 200-300 G measured in GaAs-based QD. ESR spectroscopy in the magnetic field - microwave frequency plane shows also an unexpected level anti-crossing, with an energy gap of about 50 MHz. The spectral line gives an estimation of the lower bound of the inhomogenous phase de-coherence time T_2^* of about 200 ns for individual spins in the nano-structured Si system with a Si/SiO_2 interface.[11] This is certainly a rather encouraging news for Si MOS based qubit structures. The intriguing anti-crossing effect reveals that the hybridization of the spin-up and spin-down states in a dot as the primary mechanism for ESR detection, that is likely trigged by the additional valley degree of freedom in Si. We have worked with Charlie Tahan and Rusko

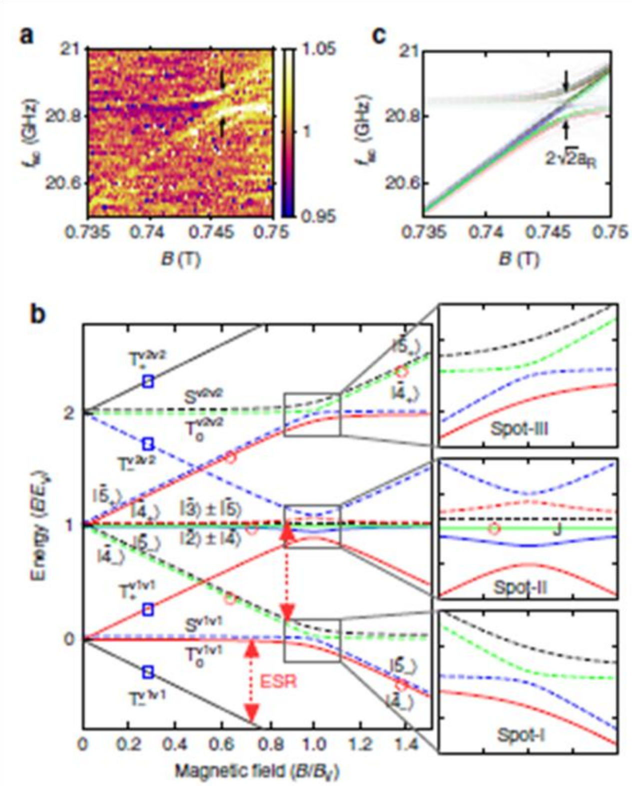

Fig. 2 **ESR spectroscopy in a Si MOS DQD.** (**a**) Normalized leakage current as a function of the external magnetic field and microwave frequency. ESR lines show anticrossing feature with a frequency gap $\Delta f_{anticross} = 60 \pm 10$ MHz (black arrows), at a position $B_V \simeq 0.746$ T (Methods). (**b**) Left panel: field-dependent energy diagram of electrons in the (1,1) charge states in case of small exchange energy: $J < |a_R|$ (see text). Dotted (blue) rectangles label the spin-blocked states that are similar to GaAs, but with valley index added; dotted (red) circles label the spin-valley-blocked states: $|\bar{4}\rangle = T_0^{v1v2} + T_0^{v2v1}$, $|\bar{4}_\pm\rangle = T_\pm^{v1v2} + T_\pm^{v2v1}$, eventually surviving for a non-ideal interface (see text). The other (non-blocked) states are: $|\bar{5}\rangle = -T_0^{v1v2} + T_0^{v2v1}$, $|\bar{5}_\pm\rangle = -T_\pm^{v1v2} + T_\pm^{v2v1}$ and $|\bar{2}\rangle = S^{v1v2} - S^{v2v1}$, $|\bar{3}\rangle = S^{v1v2} + S^{v2v1}$. Right panels: zoom in of the level anticrossing of states with different valley content due to SOC; the size of the energy gaps is given by only two dipole matrix elements, a_R, b_L (see text). (**c**) Simulated anticrossing features in the ESR spectroscopy, using the measured valley energy splitting $E_V = 86.2\,\mu eV$ and the anticrossing splitting of equation (3) (second splitting is invisible for $|b_L| << |a_R|$).

Ruscov of LPS on the theoretical understanding of the spin hybridization. A comprehensive analysis was carried out for a DQD that contains two valence electrons, along with two different valley states, under a periodic microwave perturbation. Tahan and Ruscov have specifically developed a nice spin-valley physics theory [11]. In the absence of magnetic field and microwave, there are 12 states for the (2,0)/(0,2) charge configurations, and 16 states for the (1,1) configuration. Since the experiments show that the ESR spots are independent of detuning, only the interaction of (1, 1) states are relevant. Application of a magnetic field brings three group of (1,1) states into degeneracy at different magnetic fields. Selection rules allow 14 level anti-crossings, due to spin-valley mixing, which can be induced at three locations. The matrix elements of the spin-valley mixing, due to an interface step, of all the 14 level anti-crossings were calculated. It turns out that there are only two values of matrix elements and one clearly dominates another. The coupling strengths of ESR transitions for different spin-valley hybrid states were subsequently calculated. One likely speculates the interaction of so many states would likely make the problem very complex and even unmanageable. Amazingly enough, the investigation shows that collection of allowed ESR transitions give raise only one dominating anti-crossing in the frequency and magnetic field plane.

(3) Measurement of gate noise in Si MOS QDs.

It is now becoming increasingly apparent to semiconductor QD research community that the fidelities of the electrically controlled gate operations are intimately related to the charge noise in the base materials.[1 2] Motivated by various groups in the Si qubit community, for a comparison with other materials, we have also studied the low-frequency charge noise of a typical Si MOS QD, in collaboration with Dr. Matt Borselli of HRL. Our measurement of the Si MOS QD device, around a Coulomb peak, shows 1/f power spectra density for the intrinsic gate noise. The noise amplitude reduces continuously as the temperature is reduced from

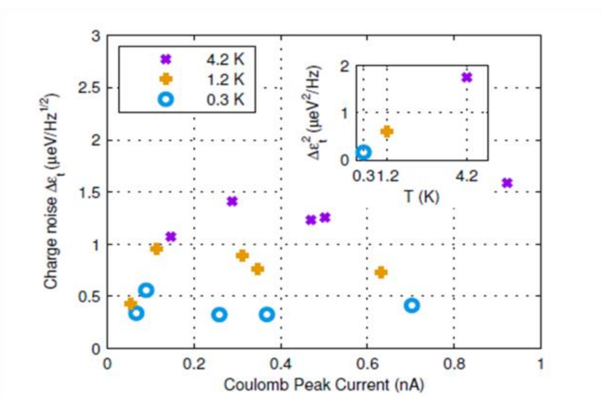

Fig. 3 Temperature dependence of the normalized charge noise, measured as a function of the Coulomb oscillation peak height by choosing different bias voltages. (inset) Averaged normalized charge noise for each temperature from the data in the main panel.

4.2K to 0.3K. For the purpose of comparison with devices made out of other materials, we have obtained the calibrated noise at the frequency of 1 Hz. The gate noise is determined to be 0.2 micro-eV per root Hz at a temperature of about 0.3 K, after using an innovative analysis procedure. This noise figure turns out to be a bit smaller than the similar devices in SiGe QDs. This is indeed another encouraging news for the further development of exchange-only qubits in Si MOS structures.

(4) Establishment of spin states read-out

Since the logic qubit is formed by individual spins, it is critical for us to do projective read-out of the spin states. Recently, we have made an important advancement to use pulse sequences to read the spin states. To facilitate the read-out and control, two separate channels of an arbitrary function generator is used to deliver pulse trains to the TQD device. The two synchronized pulses allow us to pulse from one arbitrary point to another in the two-dimensional charge stability plane. To sense the spin states, Pauli spin blockade is used. Since the triplet states of the two of coupled spins T(1,1) are not allowed to make a transition to the singlet S(2,0), the singlet and triplet states of the coupled spins can be distinguished by charge configurations. Several our measurements have shown this spin read-out. First, by pulsing cyclically from (0,1,1) to (1,1,1) to (2,0,1) and back to (0,1,1), we have observed a trapezoidal pattern in the charge stability diagram, showing the absence of transitions from T(1,1) to S(2,0). From this unique pattern, we conclude that our read-out window is about 0.3 meV.[13] Second, when a short pulse about 1 μs is used to mix the singlet and triple states under the (1,1,1) charge configuration, a funnel shaped pattern is observed in the pulse-amplitude and magnetic field plane, as that reported in the literature, commonly referred as spin-funnel.[12,13] Third, a spin singlet to triplet transition is observed for a charging line from (0,1,1) to (2,0,1) at around 2.5T, that further supports the above spin sensing mechanism. To more effective read-out spin states when thermal energy is comparable to the Zeeman energy, we have developed a statistical method [14], based on Markov-Modulated Gaussian Process models, to extract information about spin-dependent dynamics from random telegraph signals and the method was verified using the data collected in a GaAs device.

(5) Observation of coherent oscillations of the TQD qubit

Perhaps the most exciting development of our project is our recent excitation of coherent oscillations in our TQD devices. The system is prepared in the (0,2,1) state and is pulsed into the (1,1,1) state for exchange interaction for a pulse time t_p. A clean set of oscillations have been observed up to a few micro-seconds in the qubit occupation probability as a function of t_p, as

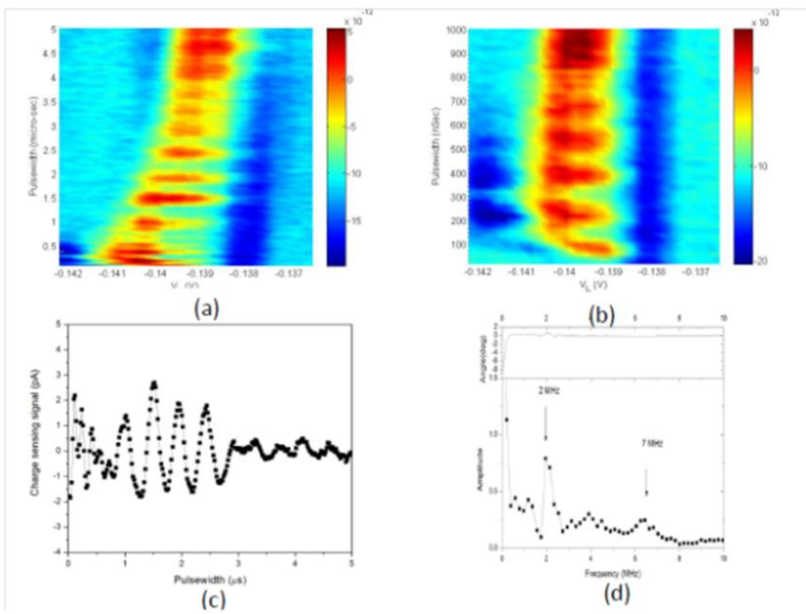

Fig. 4 Charge sensing signal as a function of pulse-width t_p and the detuning, for pulse time up 5 μs in (a) and 1 μs in (b). (c) Clean oscillations in time domain are displayed in the averaged signal as a function of t_p. (d) FFT reveals two leading frequency components of the coherent oscillations.

shown in Fig. 5. The oscillations have two frequency components of about 2 MHz and 7.5 MHz. As our pulse duty-cycle is very small, any artificial incoherent charge effect is not likely. Furthermore, any non-equilibrium effect of charge-based coherent states would expect to have a much shorter time scale, in the range of nanoseconds. Thus, these oscillations are very possibly caused by the pulse excited spin dynamics. We think the slower oscillation is likely the result of singlet and triplet mixing of one pair of spins due to hyperfine interaction while the faster oscillation is the result of the strong exchange interaction of the other pair of spins. Further

experiments and density matrix simulations will be carried out for the next funding period. We should be able to establish a better understanding of these coherent oscillations in the near future.

References

[1] D. P. DiVincenzo, D. Bacon, J. Kempe, G. Burkard, and K. Whaley, “Universal quantum computation with the exchange interaction”, Nature 408, 339 (2000).

[2] E. A. Laird, J. M. Taylor, D. P. DiVincenzo, C. M. Marcus, M. P. Hanson, and A. C. Gossard, “Coherent spin manipulation in an exchange-only qubit”, Phys. Rev. B, 82:075403, 2010. (2010).

[3] L. Gaudreau et al., “Coherent control of three-spin states in a triple quantum dot”, Nature Phys. 8, 54 (2011).

[4] J. Medford, J. Beil, J. M. Taylor, S. D. Bartlett, A. C. Doherty, E. I. Rashba, D. P. DiVincenzo, H. Lu, A. C. Gossard, and C. M. Marcus, “Self-Consistent Measurement and State Tomography of an Exchange-Only Spin Qubit”, Nature Nanotechnology, 8, 654 (2013).

[5] J. Medford et al., “The Resonant Exchange Qubit”, PRL 111, 050501 (2013).

[6] J. M. Taylor,V. Srinivasa,and J. Medford, “Electrically-protected resonant exchange qubits in triple quantum dots”, PRL 111, 050502 (2013).

[7] Andrew C. Doherty and Matthew P. Wardrop, “Two-Qubit Gates for Resonant Exchange Qubits”, PRL 111, 050503 (2013).

[8] M. Xiao, M. G. House, and H. W. Jiang, “Measurement of the Spin Relaxation Time of Single Electrons in a Silicon Metal-Oxide-semiconductor-Based Quantum Dot”, Phys. Rev. Lett. 104, 096801, (2010).

[9] M. G. House, H. Pan, M. Xiao, and H. W. Jiang, “Non-equilibrium charge stability diagrams of a silicon double quantum dot”, Appl. Phys. Lett., 99, 112116 (2011).

[10] H. Pan, M. G. House, X. Hao, and H. W. Jiang, “Fabrication and characterization of a silicon metal-oxide-semiconductor based triple quantum dot”, Appl. Phys. Lett. 100, 263109 (2012).

[11] Xiaojie Hao, Rusko Ruskov, Ming Xiao, Charles Tahan, and HongWen Jiang, “Electron Spin Resonance and spin-valley physics in a silicon double quantum dot”, Nature Communications 15, 3860 (2014).

[12] F. A. Zwanenburg et al., “Silicon Quantum Electronics”, Rev. Mod. Phys. 85, 961 (2013).

[13] B. M. Maune, M. G. Borselli, B. Huang, T. D. Ladd, P. W. Deelman, K. S. Holabird, A. A. Kiselev, I. Alvarado-Rodriguez, R. S. Ross, A. E. Schmitz, M. Sokolich, C. A. Watson, M. F. Gyure, and A. T. Hunter, “Coherent singlet-triplet oscillations in a silicon-based double quantum dot”, Nature, 481:344, (2012).

[14] M. G. House, Ming Xiao, GuoPing Guo, HaiOu Li, Gan Cao, M. M. Rosenthal, and HongWen Jiang, "Detection and measurement of spin-dependent dynamics in random telegraph signals", Physical Review Letters, 111, 126803 (2013).

Publications

* M. G. House, H. Pan, M. Xiao, and H. W. Jiang,

Non-equilibrium charge stability diagrams of a silicon double quantum dot

Appl. Phys. Lett., 99, 112116 (2011).

* H. Pan, M. G. House, X. Hao, and H. W. Jiang,

Fabrication and characterization of a silicon metal-oxide-semiconductor based triple quantum dot

Appl. Phys. Lett. 100, 263109 (2012)

* M. G. House, Ming Xiao, GuoPing Guo, HaiOu Li, Gan Cao, M. M. Rosenthal, and HongWen Jiang,

Detection and measurement of spin-dependent dynamics in random telegraph signals

Physical Review Letters, 111, 126803 (2013).

* Xiaojie Hao, Rusko Ruskov, Ming Xiao, Charles Tahan, and HongWen Jiang

Electron Spin Resonance and spin-valley physics in a silicon double quantum dot,

Nature Communications 15, 3860 (2014).

Invited Talks

* HongWen Jiang, "Measurement and control of individual electron spins in Silicon MOS-based quantum dots", Quantum Control of Solid State Systems Workshop, Princeton, NJ, November 3, 2011.

*HongWen Jiang, "Physical implementation of quantum information processing based on individual electron spins in semiconductors", Physics Colloquium, Pomona College, December , 2011.

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Compounds: Materials, Processing, and Devices Symposium, Honolulu, Hawaii October 10, 2012.

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